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Evaluation of Pilot-Scale Pollution Control Devices for Hazardous Waste Incineration

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ABSTRACT

The paper summarizes the results of emission tests carried out on three pilot-scale air pollution control devices. The units were connected to a slip stream from the ENSCO, Inc. hazardous waste incinerator at El Dorado, Arkansas. The three units were a Hydro Sonic System wet scrubber; an ETS dry scrubber; and a Vulcan Engineering Company high temperature baghouse. The units were evaluated for their capability in removing particulate matter and HCl. Full discussion of the testing program and results is in an EPA report, Evaluation of Air Pollution Control Devices for Hazardous Waste Combustion, now undergoing final review in the Agency.

INTRODUCTION

As hazardous waste disposal practices in the country continue to evolve from land disposal to alternative treatment and destruction processes, incineration continues to grow in popularity as a waste management system. High temperature incineration can, in a matter of seconds destroy or significantly reduce a hazardous waste that might otherwise take months or years to degrade in a landfill. While the primary products of combustion in a well designed and operated incinerator are carbon dioxide and water (vapor), there are also emitted other products of combustion depending upon the characteristics of the waste material being incinerated. Some of these products of combustion are viewed as air pollutants and are regulated under various state and Federal environmental regulations. There are generally two types of air pollutants emitted by incinerators: the products of incomplete combustion of the organic waste constituents, and the ultimate oxidation products, including inorganic ash. Examples of the former type are trace amounts of the unburned original waste stream, CO, hydrocarbon, and organic acids. Examples of the latter type are HCl, NO_x, SO_x, and particualte matter. Control of the organic emissions are generally dependent upon controlling combustion conditions or utilizing an afterburner device of some sort. Control of the pollutants such as SO_x, HCl, and particulate matter is more often achieved through the use of a control device external to the combustion process. The air pollution control devices tested by EPA described in this paper are such external devices.

There are in use throughout the Country many devices for controlling air pollutants from hazardous waste incinerators. The primary control devices currently in use are scrubbers and electrostatic precipitators. Also increased attention is being given to various types of fabric filters and dry scrubbers as control options. While it is recognized that conventional air pollution control devices can achieve current regulatory requirements, it is also recognized that new and advanced devices may offer advantages, especially in the collection efficiencies for small particulate. The purpose of this project was to evaluate three of the advanced devices operating in a slip stream from a commercial scale hazardous waste incinerator.

UNITS SELECTED

After a literature survey and extensive personal contacts by the contractor for this work, Research Triangle Institute, the following three units were selected for inclusion in the program:

- steam hydro-scrubber - Hydrosonics, Inc.
- dry scrubber - ETS, Inc.
- high temperature baghouse - Vulcan Hi Tac Unit

A fourth system, a Ceilcote wet ionizing scrubber was also selected for inclustion in the project. However, because of damage sustained during start up procedures for the tests, the Ceilcote unit was not available for a full evaluation.

Because of the many constraints involved in setting up tests such as these, the units selected should certainly not be considered to be the only advanced designs available, or even necessarily the most advanced designs available. Many companies contacted were not able to participate either because they did not have suitable pilot equipment, or because their pilot units were already committed to other projects. However, the units selected can be considered as representative of new approaches to emissions cleanup.

TESTING APPROACH

The specific goals of this study were to examine the cleaning capabilities of each control device under specified operating conditions. The pollutants to be monitored were (a) particulates, total mass and as a function of particle size, and (b) hydrochloric acid (HCl).

The host facility for the project was the ENSCO, Inc. hazardous waste incinerator located in El Dorado, Arkansas. This facility consists of a rotary kiln for incinerating solid wastes and a thermal oxidation unit for injection of liquid wastes. Natural gas is used to insure that minimum temperature necessary for complete destruction of wastes is maintained. During the time these tests were being carried out, the plant was incinerating PCB contaminated oils and capacitors. The plant typically operates 24-hours per day, 7 days per

week. Generally, waste of a specific class was accumulated on-site until sufficient quantity was available for burns of at least one day; this allowed for steady state conditions to be achieved and maintained.

Gases exiting the thermal oxidation unit pass through a large chamber in which large particles are removed. The gases are then drawn into the plant wet scrubber and exhausted to the atmosphere. The gases to be cleaned up by the pilot scale devices were drawn into a bypass stack by the fans on the air pollution control device (APCD). The placement of the slip stream resulted in withdrawing a gas containing a lower concentration of the larger particulate matter than exists in the main duct. Since the primary objective of the study was to measure the control of fine particulate, the placement of the slip stream, which generated a high percentage of sub-micron particulate matter, was believed to help rather than hinder the study.

Gases withdrawn from the bypass stack passed through a dry bottom quench chamber to reduce the temperature of the gas to about 300°C to protect the pilot units (see Figure 1) . The gas then passed through a horizontal 30 cm (12 inches) ID duct and into the APCD. The inlet sample ports located in this duct met all requirements of EPA Method 5.

During the time the tests were carried out, the plant was primarily incinerating PCB contaminated oils and PCB capacitors. This produced high levels of hydrogen chloride (7,000 + 12,000 ppm) and a very sticky particulate. The sticky particulate matter contributed to many operational problems encountered during the tests.

TEST METHOD DESCRIPTION

Testing was performed using two techniques. The first, using EPA Method 5 techniques, sampled for total particulate mass concentrations as described in the Federal Register. The "back half" of the train (i.e., the impingers) was used to capture gaseous HCl, and was analyzed using a chloride-specific ion electrode to infer HCl concentrations in the gas stream. This method provides timely, economical analysis of uncomplexed chloride ion in solution. Samples were simultaneously obtained at the inlet and outlet sites according to the U.S. EPA Method 5 description.

Particle size characterization of the control device efficiency was inferred using cascade impactors at the inlet and outlet sites. Due to the large difference in particulate loading between the two sites, it was not possible to obtain simultaneous impactor samples; typically, 5-7 minutes operation at the inlet site produced optimum stage loadings, primarily at the last two stages of the Andersen impactors. Operation of 60-90 minutes was required for collection of adequate sample at the outlet site; these samples were arranged to coincide with one or more Method 5 sampling runs.

Initial considerations in the development of this project included selection of an incinerator that would be representative of hazardous waste incineration

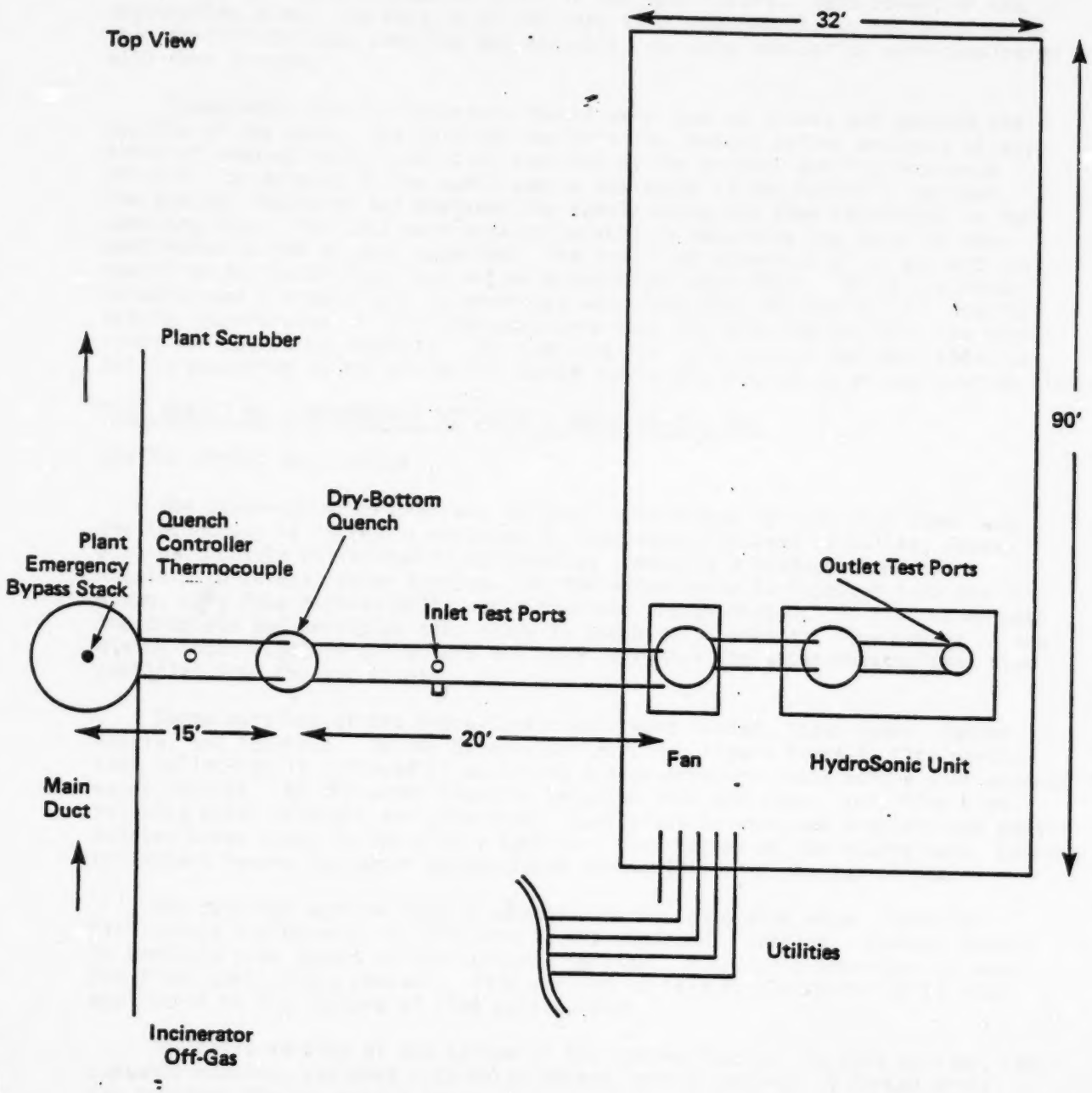

Figure 1. General relationship of sampling site.

production facilities, and advanced control devices which might be readily obtained as full-scale production units in the near future. Development of the engineering plans, the details of the test site development, selection of suitable control devices, sampling and analysis, and data evaluation were considered with this in mind.

Independent quality assurance checks were used to assess and enhance the quality of the data. The chloride analysis was checked before analysis of any batch of samples using a solution supplied by the project Quality Assurance Officer. An aliquot of the audit sample was added to the Method 5 impinger. The analyst recovered and analyzed the sample using the same techniques as for sampling runs. The data were back-calculated to determine the chloride concentration in the aliquot supplied. The specified tolerance of 10 percent (as specified in the QA Plan) was met or exceeded at each check. While the check solution was a simple salt in deionized water and thus did not contain possible matrix interference, it provided assurance that the chloride-specific ion electrode was operating properly. The sampling for this project was done satisfactorily according to the criteria. Contained in the project is an approved QA Plan.

TEST SERIES #1 - HYDROSONIC SCRUBBER - MARCH 15-23, 1984

CONTROL DEVICE DESCRIPTION

The steam-hydro scrubber was originally developed by Lone Star Steel and the technology is currently marketed by Hydro-Sonic Systems of Dallas, Texas. Fine-particulate collection is achieved by combining a high-pressure steam nozzle with several water nozzles. As the water spray is injected into the steam, very fine high-velocity water droplets are generated. Collisions between the droplets and particles take place in the highly turbulent flow regime of the mixing tube. Cyclone collectors are used to remove the water-encapsulated fine particles from the gas stream.

Three versions of the Hydro-Sconic APCD were tested; Steam-Hydro, Tandem Nozzle, and Supersub. In the Steam-Hydro version, Figure 3 and 4, fine particulate collection is achieved by combining a high pressure steam nozzle with several water nozzles. As the water spray is injected into the steam, very fine high velocity water droplets are generated. Collisions between the droplets and particulates takes place in the highly turbulent flow regime of the mixing tube. Cyclone collectors remove the water encapsulated particulate from the gas stream.

The Supersub version adds a subsonic nozzle, also with water injection. Particulate coalescence is initiated in the supersonic section. Further growth in particle size occurs in the subsonic section. A cyclonic separator is used for final particulate removal. This version is felt by the vendor to be most applicable to the capture of fine particulates.

The third version of the system is the Tandem Nozzle. In this version, two subsonic nozzles, equipped with water sprays, are in series. A forced draft fan provides the gas motive force.

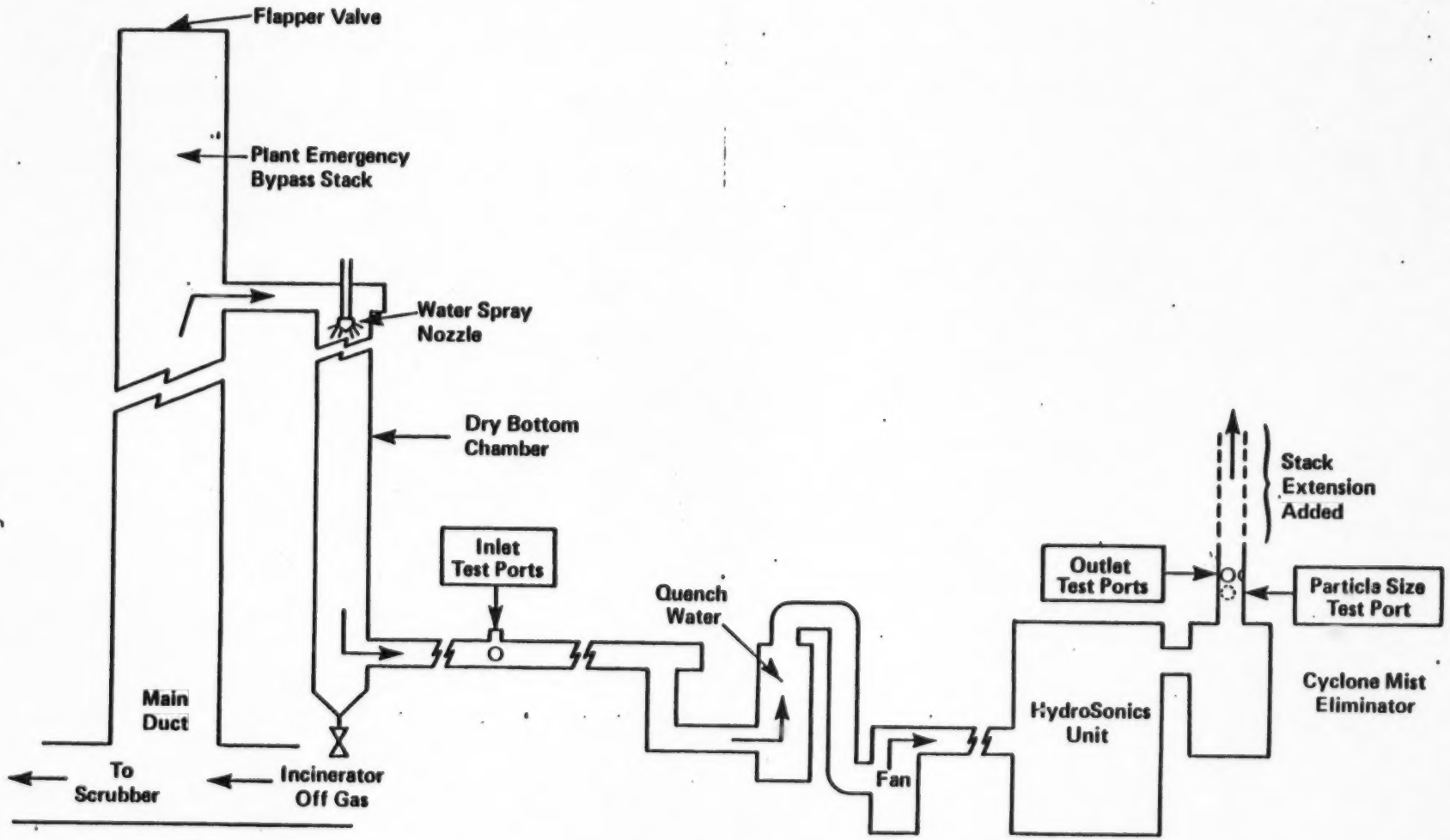

Figure 2. General relationship of sampling ports and major components of the HydroSonics system.

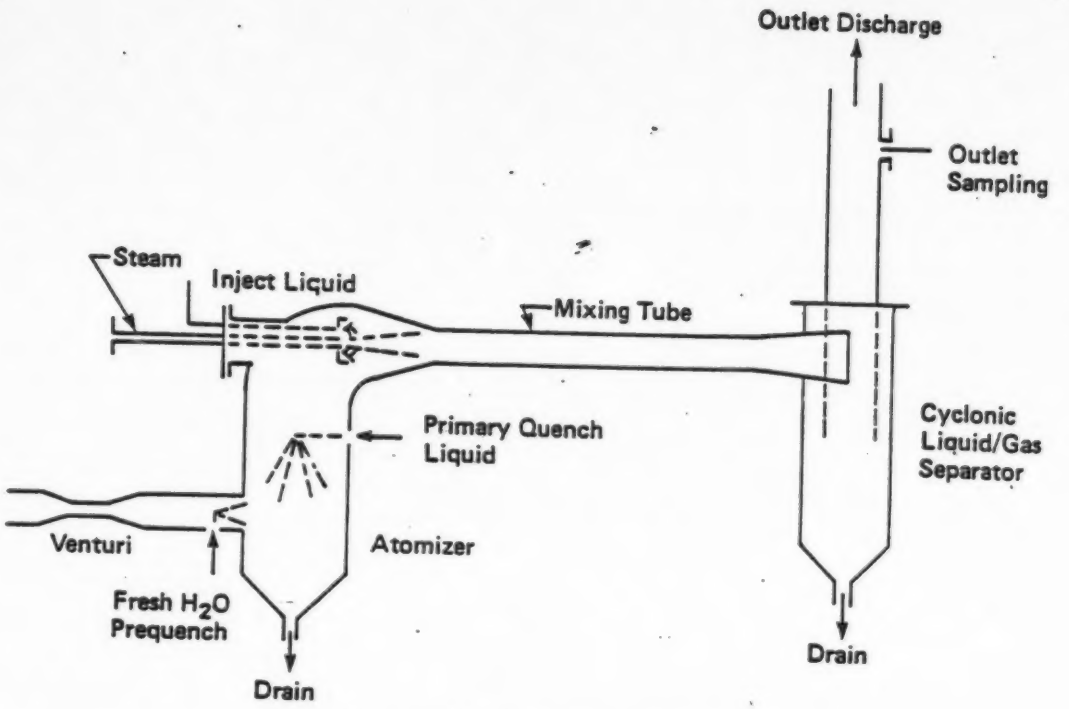

Figure 3. HydroSonics steam hydro test configuration.

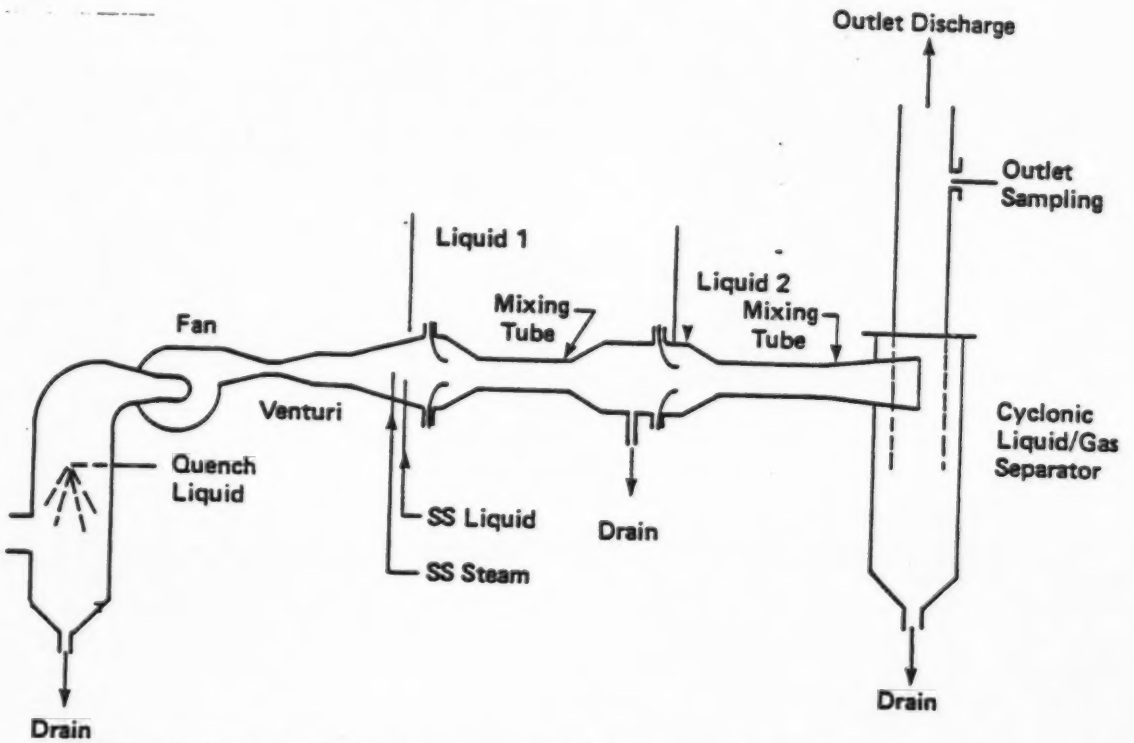

Figure 4. HydroSonics tandem nozzle (TN) and supersub test (SS) configuration.

The basic concept of all three versions is the same. Water is atomized to slightly greater than the particulate size. Turbulent contact then results in an apparent growth in the particulate size to a range that can be removed by cyclonic separators. The three versions differ in energy and water requirements and in ability to control fine particulates. The Supersub is designed to control fine (<5 micron) particulate and is the most energy intensive. The Tandem Nozzle is primarily applicable to large particulate matter. The Steam-Hydro operates in the intermediate range. Figures 2, 3, and 4 relate to the Hydrosonics Unit

TEST RESULTS AND DISCUSSION

Table 1 shows average removal efficiencies for the various operating versions of the hydrosonic units. Expanded tables are available in the full report.

With the exception of two tandem nozzle runs, chloride removal for all combinations was greater than 98 percent. Runs made using recycle water from the ENSCO scrubber show higher removal of chloride than those using freshwater. Since the recycle water contained some alkalinity, this is not surprising. In a commercial application, alkalinity would be added to the scrubbing water. Thus, chloride removals of 99 percent or better should be expected for any version of this unit.

TABLE 1 PARTICULATE AND CHLORIDE REMOVAL EFFICIENCIES: HYDRO-SONIC SCRUBBER

Configuration	Average Particulate Removal Efficiency	Chloride Removal Efficience
SH/Lo/R	81.6	99.1
SH/Lo/R	87.4	98.7
SH/Hi/R	88.2	98.8
TN/-/R	92.1	99.8
TN/-/F	86.3	96.0
SS/-/F	95.4	98.3

SH = Steam Hydro; TN = Tandem Nozzle; SS = Supersub configurations.
Hi = High energy (0.19 lb stream/lb gas).
Lo = Low energy (0.14-0.15 lb steam/lb gas).
F = Freshwater; R = Recycle water injection.

Particulate removal efficiency ranges from about 82 to 88 percent for the Steam-Hydro and Tandem Nozzle versions. The Supersub version achieved a particulate removal efficiency of about 95 percent. It should be noted that these removal efficiencies refer only to the gas stream brought into the APCD and not to the efficiency that might be obtained on the entire gas stream from the ENSCO incinerator. Since the APCD connection to the main gas duct should have

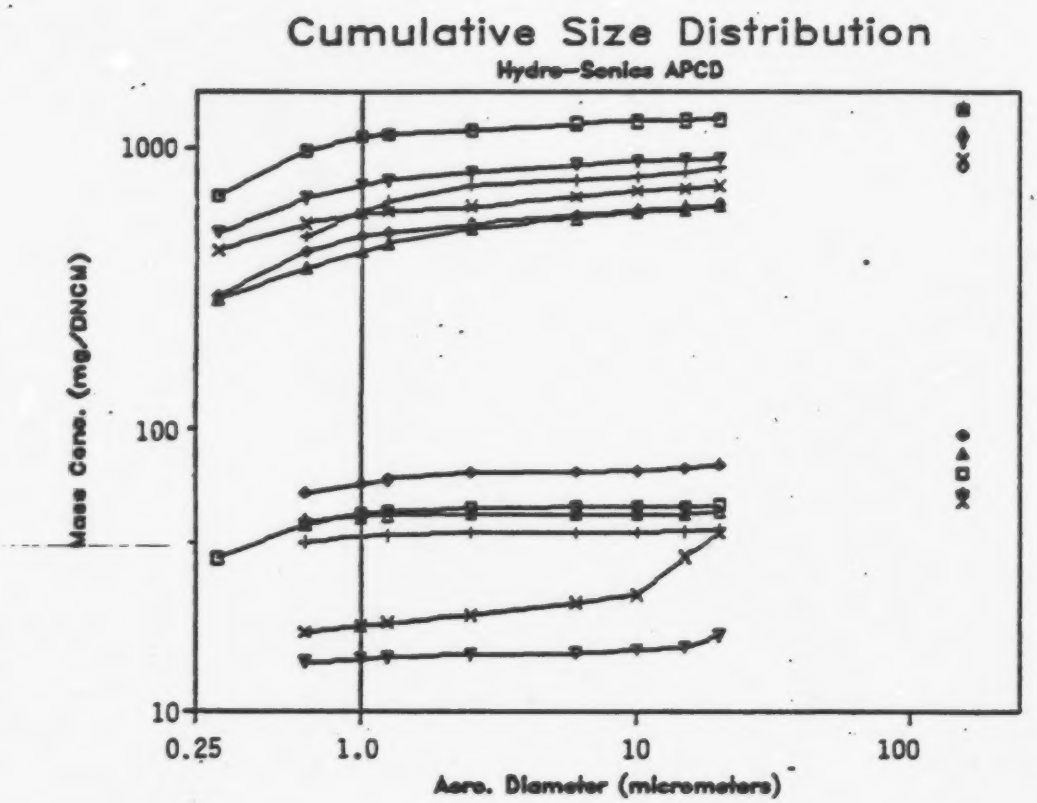

Figure 5. Cumulative particle concentration vs. particle diameter: Hydrosonics APCD.

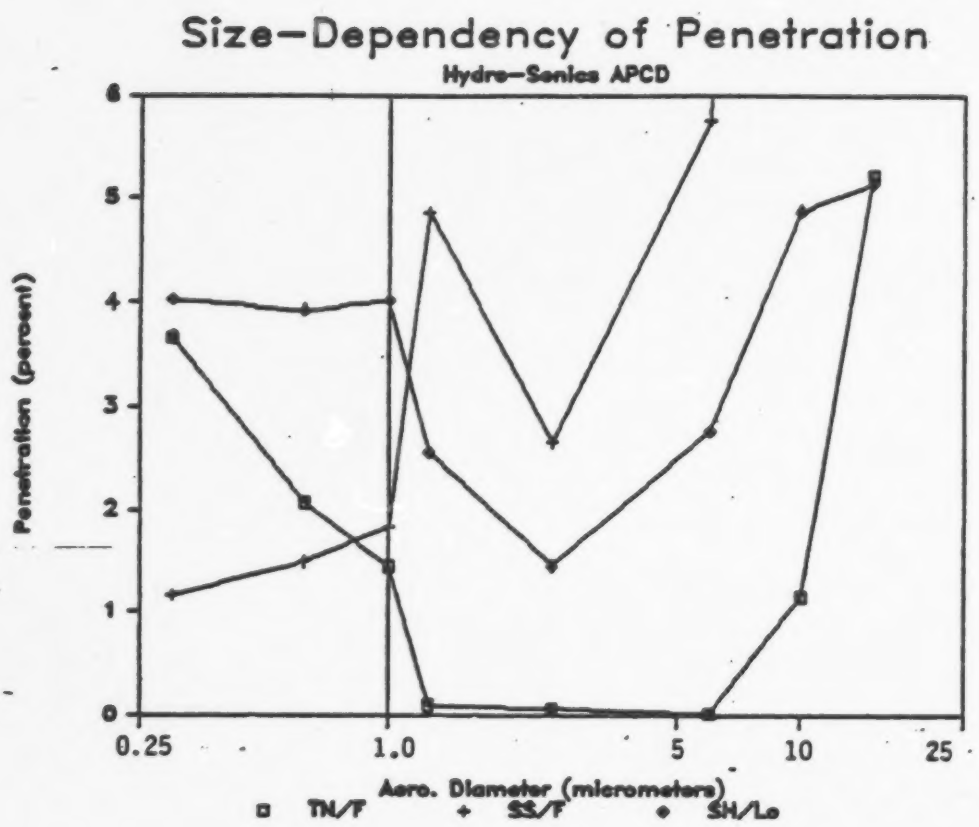

Figure 6. Penetration (size-based) vs. particle diameter: Hydrosonics APCD.

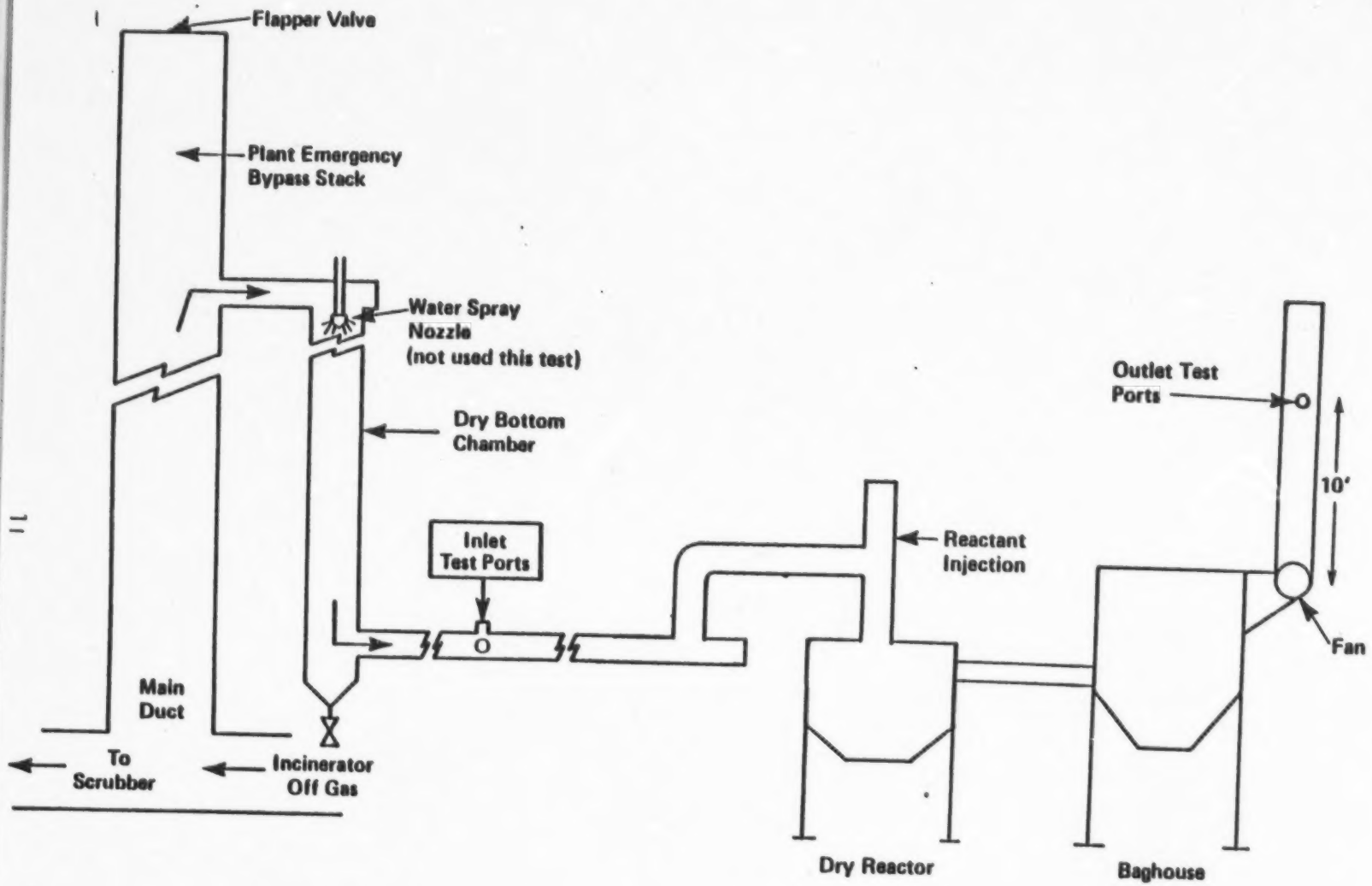

Figure 7. General relationship of sampling ports and major components of the ETS system.

resulted in a bias toward the smaller particles, we would expect that substantially higher removal efficiencies would have been obtained if the APCD had been treating the unbiased gas stream.

The plot of the cumulative mass a function of particle size (Figure 5) shows that the large fraction of the particulate matter exists below 1 micrometer, whether at the inlet or outlet of the control device. The particle penetration, as a function of particle size (Figure 6), shows wide variability, partially due to the different operating conditions shown, and partially due to the need for more impactor data. These data indicate that the Supersub configuration is the most effective of the versions tested for control of submicron particulate matter.

TEST SERIES #2 - ETS DRY SCRUBBER - April 6-26, 1984

CONTROL DEVICE DESCRIPTION

The ETS, Inc. dry scrubber is a prototype research unit that had previously been installed at the company's Travelers Rest, South Carolina facility. ETS, Inc. is located in Roanoke, Virginia. As shown in Figure 7, the unit consists of two main components--the dry reactor system and a baghouse filtration system. For these tests, a pulse jet baghouse fitted with Nomex® fabric cartridges was used. Other types of fabric filtration systems could be used.

The basic operating principles are as follows. Flue gas is directed cyclonically into the reactor where the rotating slinger unit delivers the dry reactant (in this case 100 percent less than 200 mesh) perpendicular to the flue gas which results in intimate contact of the two. An internal recirculator with no moving parts is located above the slinger, thus increasing the contact time and the likelihood of reaction.

The slinger then directs the resulting dry compounds down and into the expansion section where some of the reacted material is removed. The remaining particulate matter carries over to the fabric filtration system where the finer particulate matter and additional acid gas is removed. The cleaned gas was exhausted through a 30 cm (12 inch) diameter stack by an induced-draft fan located between the baghouse and the stack.

It is important to note that this is a true dry system. The reagents utilized (lime and nahcolite) were introduced as dry powders, not as slurries.

TEST RESULTS AND DISCUSSIONS

The removal efficiencies for particulate matter and chlorides are shown in Table 2.

Due to limitation in the feed equipment, nahocolite was injected at much lower stoichiometric ratios. Thus, it is not possible from the data to compare HCl removal efficiencies at equivalent lime and nahcolite stoichiometric ratios. The HCl removal efficiency does not appear to correlate with the

Table 2 SUMMARY RESULTS: ETS UNIT

Reactant used	Stoichiometric ratio	Run Number	HCl			Particulates		
			Inlet (lb/hr)	Outlet (lb/hr)	Efficiency percent	Inlet (lb/hr)	Outlet (lb/hr)	Efficiency percent
Lime	2.80	1	23.03	0.310	98.7	1.390	0.124	91
Lime	4.53	2	14.54	1.597	89.0	1.609	0.043	97
Lime	4.50	3	14.65	0.293	98.0	1.710	0.065	96
Lime	6.61	4	9.98	0.082	99.2	0.873	0.046	95
Lime	8.71	5	7.57	0.086	98.9	0.792	0.041	95
Lime	8.07	6	8.17	0.036	99.6	3.492	0.058	98
Lime	5.29	7	6.23	0.013	99.8	0.748	0.074	90
Lime	1.94	8	16.99	7.432	56.3	1.627	0.039	98
Lime	2.42	9	13.59	2.847	79.1	5.295	0.104	98
Nahcolite	0.70	10	12.58	0.850	93.2	2.502	0.100	96
Nahcolite	0.53	11	16.43	2.957	82.0	1.612	3.920	(1)
Nahcolite	0.87	12	10.12	4.580	54.7	1.765	0.424	76
Nahcolite	–	13	(2)	7.252	(2)	1.215	0.301	75
Nahcolite	0.56	14	15.59	7.206	53.8	1.511	0.228	85
Nahcolite	1.73	15	10.72	3.423	68.1	0.778	0.135	83
Nahcolite	0.98	16	18.80	12.576	33.1	0.918	0.567	38

[1]Torn baghouse cartridge

[2]Sample bottle broken and sample lost before analysis.

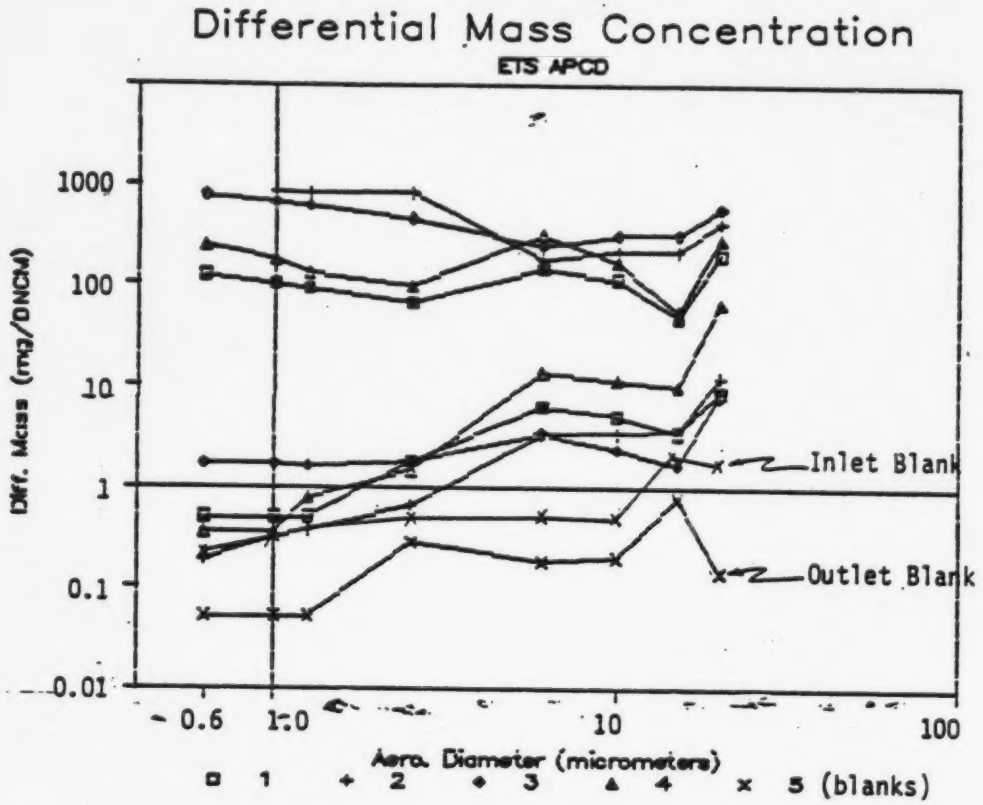

Figure 8. Differential particle mass concentration: ETS unit.

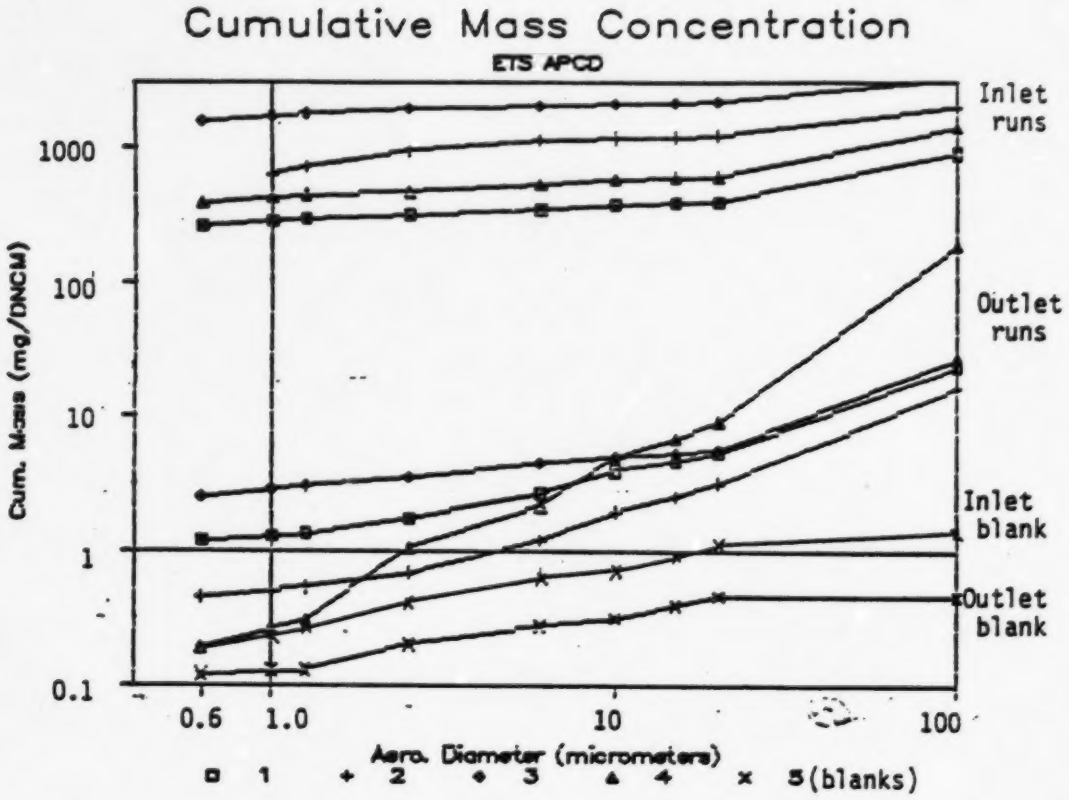

Figure 9. Cumulation particle concentration: ETS unit.

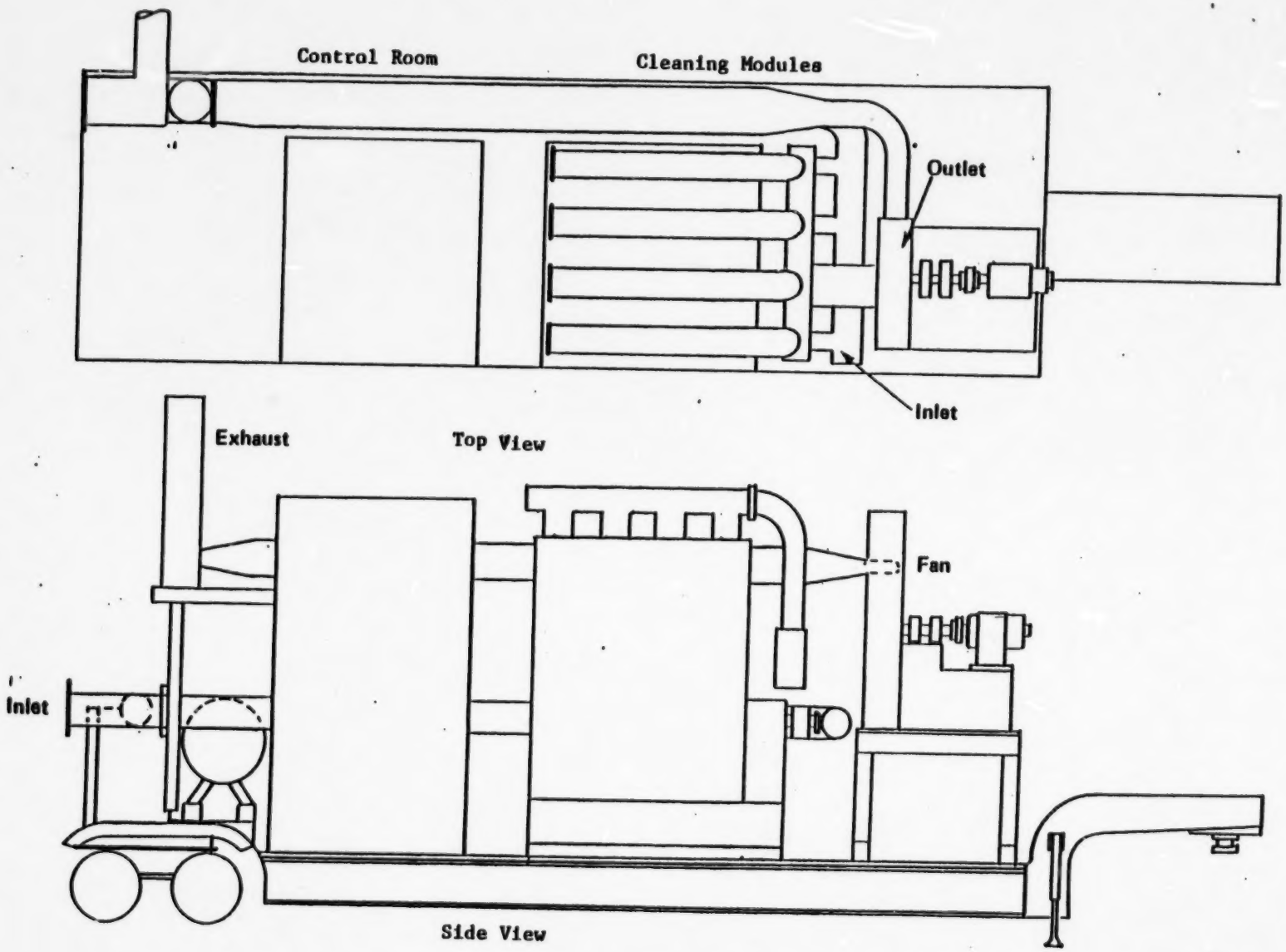

Figure 10. Schematic of Vulcan Hi-Tac mobile unit.

nahcolite/HCl stoichiometric ratio up to a ratio of 1.7. Therefore, from these tests, it is not possible to determine the nahcolite/HCl ratio required to achieve 99 percent HCl removal. It is now known if the high percentage (~44) of inerts affected the reactivity of the material.

Given in Table 2 are the removal efficiencies for total particulate matter. The efficiencies for the first ten runs were all greater than 90 percent with most in the 95 to 98 percent range. It should be noted that, due to the bias toward smaller particles caused by the slip stream sample withdrawal, this is the removal efficiency for the finer particles in the ENSCO incinerator exhaust gas. Since the unit would be expected to remove the larger particles more easily, the removal efficiency for the total gas stream would be expected to be even higher.

It is suspected that the low efficiencies measured for Runs 11 through 16 were due to persistent difficulties in sealing the cartridges in the baghouse. In addition, a tear was discovered in one cartridge after Run 11. We do not believe, therefore, that the particulate removal efficiencies reported for Runs 11 through 16 accurately reflect the capabilities of the unit.

The particulate control capability of the ETS unit as a function of particle size was also determined. The cumulative (see Figure 8) and differential (see Figure 9) mass distribution for the four sampling runs and a blank impactor set were calculated. Comparison of inlet and outlet runs should be done with caution due to sampling time differences as in the previous testing.

TEST SERIES #3 - VULCAN HI-TAC - May 14-25, 1984

CONTROL DEVICE DESCRIPTION

The Vulcan Engineering Hi-Tac (high temperature air cleaning) unit, supplied by Vulcan Engineering, Pittsburgh, Pennsylvania, is designed for high temperature filtration of particulate matter from polluted gas streams. It is specifically designed for temperatures of 600-1300°F with excursions to 2000°F. The effective air-to-cloth ratio is claimed to be 15:1 and greater. The mobile unit contains four cleaning modules, each of which houses four removable cartridge elements. Each element consists of a metallic reinforcing framework covered with stainless steel mesh whose weave may be varied, depending on the emissions source. Gas motive force is provided by an induced draft fan at the outlet manifold of the cleaning modules. A programmable controller activates the cleaning devices, which include air knives and vibrators (two modules), and pulsers and rappers (two modules). Compressed air is provided by a two-stage compressor on the 47 foot double drop tandem axle trailer. The timing of cleaning may be linked to specified time intervals or module pressure drop, or it may be operator initiated. A schematic of the unit is shown in Figure 10.

TEST RESULTS AND DISCUSSION

The total removal efficiencies for particulate matter and chloride are shown in Table 3.

TABLE 3 VULCAN HIGH TEMPERATURE BAGHOUSE EFFICIENCY SUMMARY

Run number	Date	Particulates			Chlorides			Lime Injection
		Inlet Loading (lb/hr)	Outlet Loading (lb/hr)	System Efficiency (Percent)	Inlet Loading (lb/hr)	Outlet Loading (lb/hr)	System Efficiency (Percent)	
1	5/16/84	1.411	0.928	34.2	27.65	44.85	--	2 kg/hr
2	5/17/84	3.666	0.253	93.1	31.97	42.27	--	precoat
3	5/17/84	3.848	0.368	90.4	19.44	25.29	--	2 kg/hr
4	5/17/84	4.148	0.310	92.5	30.66	23.00	25.0	precoat
5	5/18/84	2.537	0.148	94.2	21.75	10.77	50.5	precoat
6	5/18/84	1.557	0.244	84.3	22.71	22.57	0.1	precoat
7	5/18/84	2.511	0.268	89.3	31.38	38.59	--	precoat
8	5/21/84	3.732	0.940	74.8	25.33	12.87	49.2	5.4 kg/hr
9	5/23/84	2.303	0.230	90.0	23.49	23.20	1.2	precoat
10	5/23/84	5.109	0.084	98.4	19.13	19.21	--	precoat

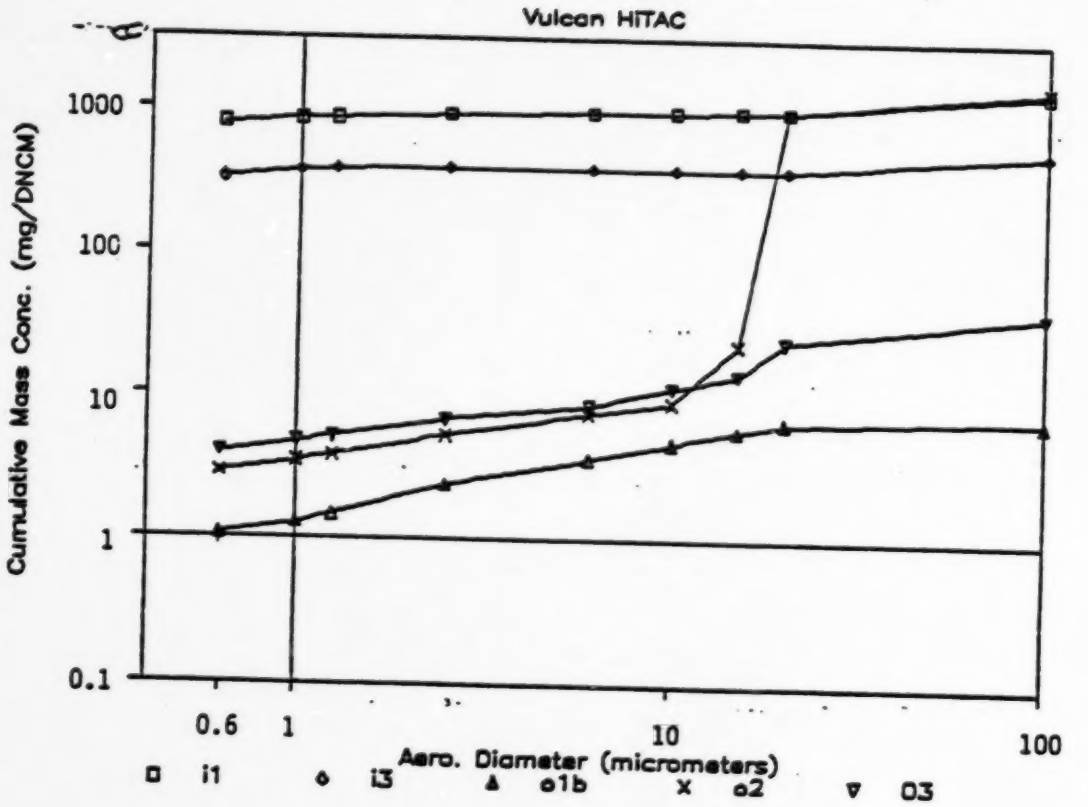

Figure 11. Cumulative mass concentration vs. particle size: Vulcan unit.

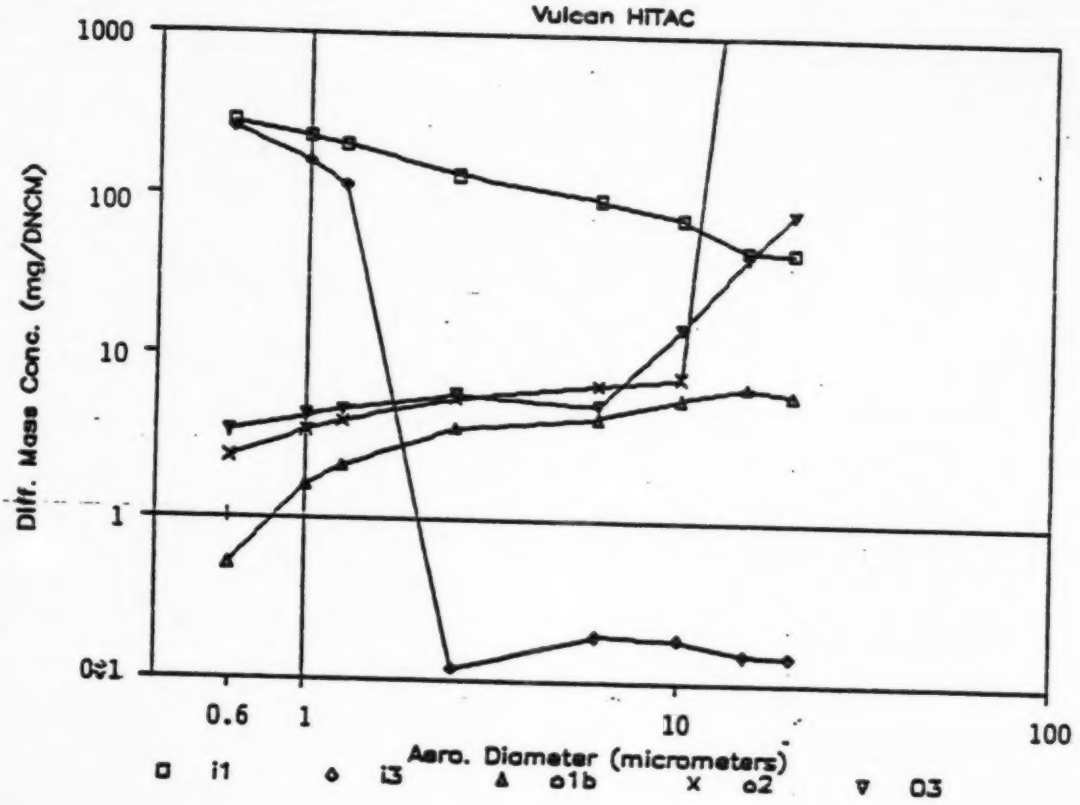

Figure 12 Differential mass concentration vs. particle size: Vulcan unit.

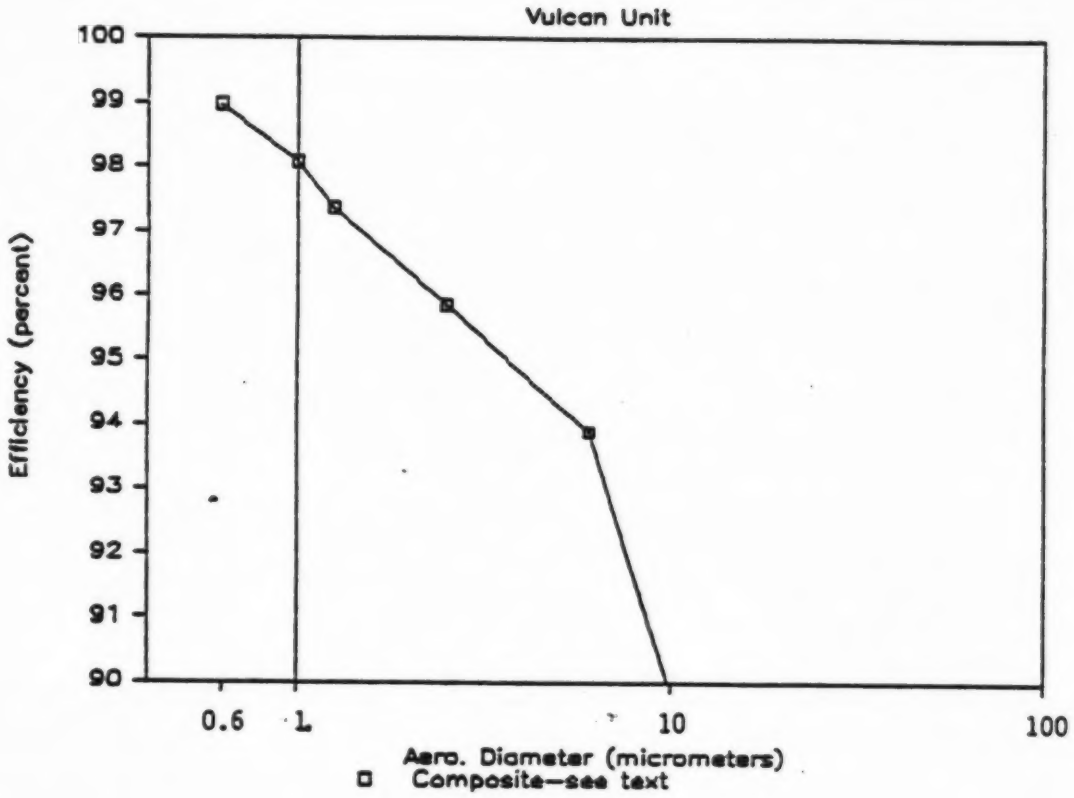

Figure 13 Efficiency of particulate matter removal vs. particle size: Vulcan unit.

The high concentration of fine, sticky particulate matter at the APCD inlet sampling port complicated sampling and required special attention by the sampling personnel. The Method 5 filters tended to clog before the scheduled end of testing, and the lower impactor substrate particulate catch was in well-defined columns.

Several parameters measured at the inlet test port exhibited substantial variability. For example, the gas temperature measured at this point ranged from 650°F to 865°F. Since similar variability was noted on ENSCO's process control instruments, it is felt that this variability will have to be accommodated by any control device used on this type source.

As can be seen, removal efficiency for particulate matter is quite erratic, varying from 34 percent to 98 percent. Excluding run number 1, the average removal efficiency is 89.7 percent. Inspections of the cartridges before and after test runs indicated that cake formation on the filter fabric was not reliable. During several inspections following cartridge cleaning, it was observed that a very large portion (about 70 percent) of the fabric surface was still covered by the filter cake, with about 20 percent of the surface clean down to the fabric. Obviously, the sticky particulate interferred with proper cake formation and filter cleaning. It is possible that fabric weave changes or precoating of the fabric might correct this difficulty. The test program was not designed to adequately explore these options.

The average gas temperature at the inlet to the unit was 750°F, well above the limits allowed by conventional baghouses. The unit did not demonstrate effective control of HCl. This is not surprising since the unit was not designed for this purpose. The small amount of lime used as filter precoat was not effective. However, the data indicate that the combination of the Hi-Tac with a dry scrubber system might produce effective control of particulate matter and HCl.

Recognizing the difficulties cited above for particulate control, we have attempted to assess, with much trepidation, the removal efficiency at various particulate size ranges. The cumulative (Figure 11) and differential (Figure 12) mass concentration distributions for two inlet, two outlet, and the blank outlet runs were plotted. Inlet run number 2 (5/18/84) was not included since it had an unreasonably large (360 mg) mass increase on the filter which influences the entire distribution determined. The differential mass distribution for outlet run number 2 is also distorted due to an unreasonably large mass increase on Stage 1.

An efficiency distribution (Figure 13) was constructed using data from inlet run number 1, averaged with the lower three standard points from inlet run number 3. The outlet distribution was calculated using the average of data from runs 2 and 3 for the lower five standard diameters and the value from run 3 at 10 micrometers.

These data indicate 98 percent or better control of particles of less than 1 micrometer.

In summary, the test results indicate that effective control of the fine particulate generated by hazardous waste combustion may be achievable by the Hi-Tac unit. Additional development work to address the problems of sticky particulate will be required.

CONCLUSIONS

1. All versions of the Hydro-Sonic units tested achieved excellent HCl control. Ninety-nine percent of HCl was obtained without adding additional alkalinity to the ENSCO scrubber recycle water. With additional alkalinity, any of these units should be capable of well over 99 percent HCl removal.

2. The Tandem Nozzle SuperSub Model 100 achieved the best particulate removal of the three Hydro-Sonic units tested.

3. The ETS dry scrubber achieved both high removal efficiencies for HCl and particulate.

4. The ETS scrubber reagent consumption, hydrated lime, appears to be high (3 moles lime per mole HCl) but cannot be stated with confidence since no attempts were made to improve utilization through reagent recycle.

5. The ETS unit does not presently have capability to adjust reagent feed rate to accommodate rapidly varying HCl content in the gas to be treated.

6. The Vulcan Hi-Tac unit is not designed to, and cannot presently, remove acid gases from the exhaust gas being treated. Therefore, it is not applicable to incinerators burning significant amounts of halogenated hazardous wastes.

7. Further development work and/or emissions testing will be required before the Hi-Tac unit demonstrates the capability to reliably control sources which might produce sticky particulate as encountered in the exhaust of the ENSCO incinerator.

8. Considerable variability was encountered in the ENSCO exhaust gas for particulate concentration, particulate size distribution, HCl concentration, flue gas moisture content, and exhaust gas temperature. It is necessary that any air pollution control device installed on a hazardous waste incinerator have design features that allow compensation for this variability.

9. Of the APCDs tested in this project, the Hydro-Sonic Tandem Nozzle SuperSub gave the best overall performance in terms of HCl and particulate removal and ability to accommodate variability in the gas stream being treated.

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